XX. *On a new Register-Pyrometer, for measuring the Expansions of Solids, and determining the higher Degrees of Temperature upon the common thermometric scale.* *By* J. Frederic Daniell, *Esq.*, *F.R.S.*

Read June 17, 1830.

In the year 1821 I published in the Journal of the Royal Institution* an account of a new pyrometer, and the results of some experiments with it, which were the means of correcting the highly erroneous notions which had, up to that time, been generally entertained of the degrees of temperature beyond the boiling point of mercury. The instrument was capable of affording correct determinations, connected in an unexceptionable manner with the scale of the mercurial thermometer; but, although applicable to scientific investigation in careful hands, it could be inserted only into experimental furnaces of a particular construction, which greatly limited its use. The great desideratum still remained of a pyrometer, which might universally be applied to the higher degrees of heat, as the thermometer has long been to the lower; and which, in addition to its use in delicate researches, might effect for the potter, the smelter, the enameler and others, in the routine of their business, what the latter daily performs for the brewer, the distiller, the sugar-refiner, and the chemist.

I shall now have the honour of laying before the Royal Society a description of a contrivance which, I trust, will be found to answer all the desired purposes; and which, while simple enough to be intrusted to the hands of common workmen in every variety of fire-place, I hope to prove, by the results of my experiments, to be sufficiently delicate to extend considerably our knowledge of the expansion of metals, upon which so much labour has been bestowed by some of the first philosophers.

I was not aware, at the time when I wrote the account above referred to, that the subject had been previously investigated by M. Guyton de Morveau, and that he had proposed to apply the expansion of platinum as a measure of high

* Vol. xi. p. 309.

temperature, and more particularly to the purpose of connecting the indications of WEDGWOOD's pyrometer with the mercurial scale and verifying its regularity. I have since carefully studied his laborious papers in the Annales de Chimie *, and the Mémoires de l'Institut †, which appear to have been but very little known in this country; and previously to entering upon the more particular object of the present paper, I must claim indulgence for a few remarks upon the general state of the inquiry at the time when its pursuit was abandoned by that able philosopher.

M. GUYTON's pyrometer consisted of a small bar or plate of platinum 45 millimetres (1.77 inch) long, 5 millimetres (about 0.2 inch) broad, and 2 millimetres (about 0.08 inch) thick, placed in a groove formed in a piece of highly baked porcelain. One extremity of this bar rested upon the solid end, which terminated the groove, and the other pressed upon the short arm of a bent lever, the longer arm of which terminated in a point and moved on a pivot over the graduated arc of a circle; indicating by its motion any lengthening of the bar by increase of temperature. The short arm of the lever was 2.5 millimetres and the long arm 50 millimetres in length, and the latter carried a nonius by which the tenths of a degree might be read off. The whole was constructed of platinum; and a plate of the same metal was made to press, in the manner of a spring, upon the extremity of the index, to prevent any displacement when withdrawing it from the fire. The description of this instrument in the first Essay, published in the year 1803, was not accompanied by any explanatory figure; and the notice in the Annales terminates by announcing that the inventor had at that time only begun "a series of experiments to determine its march, to compare it with the pyrometer pieces of WEDGWOOD, and to ascertain the degree of confidence which might be placed in the indications of the latter." The second Essay did not appear till the year 1808, and in it M. GUYTON observes that "many persons had expressed a wish to be made acquainted with the improvements which he had made in the instrument since its first construction; and that he had determined in consequence to give a fresh description of it accompanied by drawings, which might enable artists who undertook its construction to render it comparable. He, however, thought it right to give a previous account of the labours of others in this branch of science, and

* Tome xlvi. p. 276.

† 1808, Second Semestre, tome ix.—1811, ibid. tome xii.

to remove certain errors which had prevailed up to that time concerning the pyrometer then most in use (WEDGWOOD's), and which might possibly prove most commodious, and consequently most useful, if once the degree of exactitude could be determined of which it was susceptible." The remainder of the paper is taken up with an account of the most accurate experiments upon the expansion of the metals from the time of NEWTON.

The third and last Essay was delayed till the year 1811; and in it no further description of the platinum pyrometer is to be found; but a laborious comparison,

1st, of the indications of the platinum pyrometer with those of the mercurial thermometer;

2nd, of the same pyrometer with that of WEDGWOOD; and

3rd, of the degrees determined by these instruments with those previously known of the expansion, ebullition and fusion of various substances; in a range of temperature comprising the highest degrees of the thermometric scale and the lowest of WEDGWOOD's.

Now it is very remarkable that all M. GUYTON's efforts in this paper are directed to the valuation of the degrees determined by Mr. WEDGWOOD's clay pieces; but that he carries the comparison of the platinum pyrometer by actual experiment no higher than the melting point of antimony. He clearly establishes a great error in Mr. WEDGWOOD's original estimation of his degrees to that point; and, by calculation upon this basis, continues the correction to the melting point of iron, "en admettant toujours une progression uniforme jusque dans les plus hautes températures." The experimental comparison was obviously stopped by some practical difficulty at higher temperatures; and it is easy to perceive in what this must have consisted. Platinum at a red heat becomes very soft and ductile; and the lever against which the pyrometric bar pressed, being of such very slender dimensions, would obviously be liable to bend and thus frustrate the experiment: in addition to which, I can speak from my own experience, the platinum spring plate and the centre pin would be liable to a change of texture which would impede the motion of the lever and it would finally become welded to the index; for a very moderate pressure at a high temperature would produce this effect.

The conclusion, indeed, of these Essays seems to admit that the author did

not expect that the platinum pyrometer could ever come into general use: "enfin, ces corrections ne peuvent manquer d'ajouter à l'utilité du pyromètre d'argile, soit dans les travaux chimiques, soit dans les arts; quand même le pyromètre de platine, plus exact mais moins usuel, serait réservé pour en assurer la marche, et pour servir à des recherches plus importantes."

M. Guyton, however, although he abundantly proves the incorrectness of Mr. Wedgwood's estimate of the higher degrees of temperature, is very far indeed from establishing the point at which he so earnestly laboured, namely, the regularity of the contraction of the clay pieces; or from substituting a more correct value of the degrees throughout the whole range of the gauge than the one which he so completely overturned. His comparative experiments with the platinum pyrometer, at the boiling points of mercury and linseed oil, and the melting point of antimony, led him to reduce the equivalent of each degree from 130° Fahr. to 62°.5. The zero point of the clay pyrometer was thus carried back to 517° instead of 1077°; but it seems to have escaped his notice that this zero point was declared to be a red heat visible in the day-light,—a description which cannot be mistaken, and which clearly could not be below the temperature of boiling oil, melting lead, or boiling mercury; all of which are, however, placed above it in M. Guyton's table. M. Guyton also places the melting point of silver at the 22nd degree of Mr. Wedgwood's scale instead of the 28th, which was, according to his own determination, a correction first suggested by Sir James Hall in the 9th volume of Nicholson's Journal. Taking the value of each degree at 62°.5 Fahr., it fixes this point at 1892° Fahr., which agrees very nearly with my own experiment in the paper before alluded to; but continuing the calculation up to the melting point of iron, upon the supposition of an uniform progression, the 130th degree corresponds with 8696° Fahr., which, although only about half the amount 17977° assigned by Mr. Wedgwood, is very far removed from the result of my calculation 3479°.

Nevertheless, it is a curious fact, that M. Guyton's Essay contains proof that his determination is erroneous, and that mine is a near approximation to the truth. As a collateral means of verifying the indications of instruments intended to measure high degrees of temperature, he refers to the calorimeter as capable of affording the necessary data by a calculation from the amount of heat communicated to known quantities of fire or water by bodies in a state of

incandescence; and he quotes the very exact experiments of MM. Clement and Desormes, who had in this manner determined the following points:

	By the Liquefaction of Ice. Fahr.	By the Heat communicated to Water. Fahr.
Temperature of soft iron melted	3988°	3902°
Cast iron just on the point of melting	3164°	——
Red hot iron	2732°	——
White hot ditto	3282°	——
Iron just ceasing to be luminous in day-light	——	1272°
Melted copper	——	2294°

My own determinations of the melting point of cast iron, 3479°, of that of copper, 2548°, and of a red heat, about 1000°, agree, very closely and satisfactorily with these results, with which I was unacquainted at the time of my experiments. M. Guyton's remark upon the latter is: "Il suffit de jeter un coup-d'œil sur les résultats, pour recueillir de nouvelles preuves univoques de la nécessité de réduire les valeurs données par Wedgwood aux degrés de son pyromètre. Mais je ne crains pas de dire que ces réductions sont ici portées trop loin, ainsi qu'on peut en juger en les rapprochant de celles auxquelles j'ai été conduit par l'ensemble des expériences rapportées dans cet essai. Ce n'est pas que je veuille répandre des doutes sur l'exactitude des observations dont je dois la communication aux deux habiles chimistes ci-dessus cités; mais il est aisé de faire voir que la différence des résultats est due, pour la plus grande partie, à la différence des procédés; de sorte que les évaluations qu'ils ont données aux degrés de l'échelle de Wedgwood, peuvent, en dernière analyse, et en prenant les termes moyens dans la latitude que comportent des opérations aussi délicates, servir plutôt à confirmer qu'à détruire le systême de correction que j'ai établi."

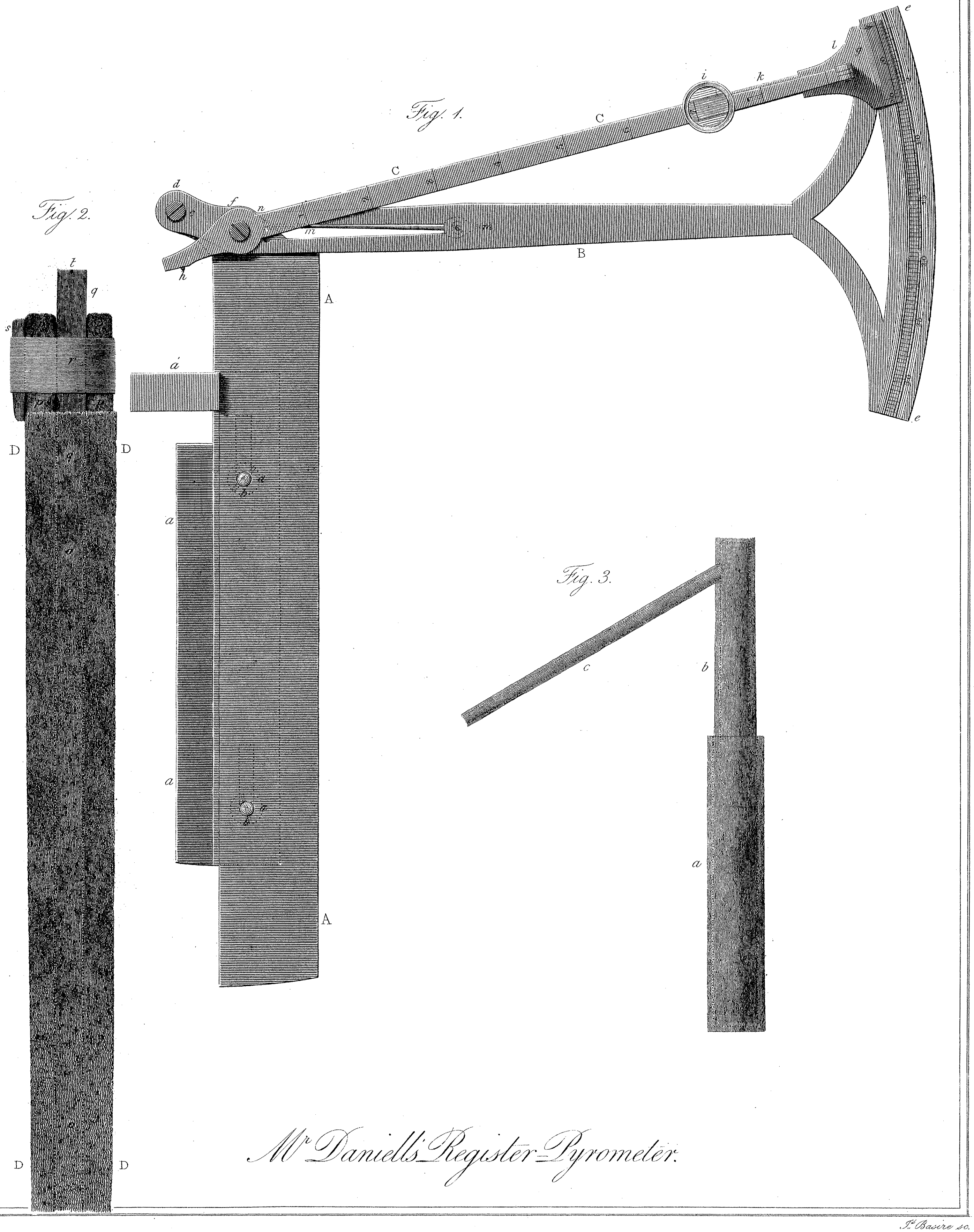
It is worthy of observation, that had the degrees of Wedgwood's pyrometer been valued from this determination of the fusing point of iron, the result would have better corresponded with the whole series of phenomena. Instead of 130° Fahr. as fixed by the inventor, or 62°.5 as corrected by M. Guyton, they would have been estimated at about 20° Fahr.; and taking Mr. Wedgwood's original determination of the fusing point of silver at 28° of his scale and the zero point at 1077°, the former would come out about 1650°. By raising the zero point a little, (and it is much more probable that the temperature of a red heat fully

visible in the day-light is above 1077° than below it,) we arrive at something like an approximation to the truth. These wide discrepancies, and the practical disuse of both Mr. Wedgwood's and M. Guyton's pyrometers for a long time past, prove the expediency of further investigating a subject of so much interest and importance.

The pyrometer, which I shall now proceed to submit to the judgement of the Society, consists of two distinct parts, which I shall designate as the Register and the Scale.

The first is a solid bar of black-lead earthenware, eight inches long, seven-tenths of an inch wide, and of the same thickness, cut out of a common black-lead crucible. In this a hole is drilled three-tenths of an inch in diameter, and $7\frac{1}{2}$ inches deep. At the upper end of this bar and on one of its sides about six-tenths of an inch in length of its substance is cut away to the depth of half the diameter of the bore. When a bar of any metal $6\frac{1}{2}$ inches long is dropped into this cavity, it rests against its solid end; and a cylindrical piece of porcelain about $1\frac{1}{2}$ inch long, which I shall call the index, is placed upon the top of it, which projecting into and beyond the open part, is firmly confined to its place by a ring, or strap of platinum; which passing round the black-lead bar and over the piece of porcelain, is made to press upon the latter with any required degree of tension by means of a small wedge of porcelain inserted between the bar and the strap on the side of the former. It is obvious that when such an arrangement is exposed to a high temperature, the metallic bar will force the index forward to the amount of the excess of its expansion over that of the black-lead, and that when again cooled, it will be left at the point of greatest elongation. It may also be observed, that the exact indication of this amount is not in the slightest degree interfered with by any permanent contraction which the black-lead may undergo at high degrees of heat; as any such contraction will take place at the moment of the greatest expansion of the metal, and the index will still mark its point of furthest extension upon this contracted basis.

The problem now consists in the accurate measurement of the distance which the index has been thrust forward from its original position; and although the amount can in any case be but small, there is no reason why it may not be determined with the same precision as is now commonly attained in similar quantities in astronomical and geodetical operations. For this purpose the



Mr Daniell's Register-Pyrometer.

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scale is constructed of two rules of brass, accurately joined together at a right angle by their edges, and fitting square upon two sides of the black-lead bar, and of about half its length. At one end of this double rule a small plate of brass projects at a right angle, which plate, when the two sides of the former are applied to the two sides of the register, is brought down upon the shoulder formed by the notch cut away at its upper end, and the whole may be thus firmly adjusted to the black-lead bar by three planes of contact.

On the outside of this frame another brass rule is firmly screwed down, which projecting beyond it, and bending a little so as to bring its end opposite to the cavity in the black-lead bar when applied to it, supports a moveable arm exactly $5\frac{1}{2}$ inches long, turning at its fixed extremity upon a centre, and at its other carrying an arc of a circle, accurately divided into degrees and thirds of a degree, whose radius is exactly 5 inches. At the centre of this circle upon the arm, and of course at the distance of half an inch from the centre of motion, another lighter arm is made to turn, one end of which, being the exact radius of the circular arc, carries a nonius with it, which moves upon the face of the arc and subdivides the former graduation into minutes. The other end crosses the centre; and at the exact distance of one-tenth of the radius, or the distance between the two centres of motion, terminates in an obtuse steel point turned inwards at a right angle. These graduations and distances are laid down with the greatest precision by Mr. TROUGHTON's dividing engine. This part of the apparatus may be regarded as a pair of proportional compasses attached to the end of the brass rule and frame, whose longer legs carrying the arc and nonius are to its shorter as ten to one; and the opening of the latter being regarded as a chord of a small circle, is magnified in the same proportion by the former, and measured upon the scale. A small steel spring let into the larger arm is made to press upon the smaller, so as to adjust the nonius to the commencement of the graduation; and when forced back it tends to restore it to its original position.

The annexed figures, in which all the parts are drawn of their real dimensions, will assist the comprehension of the preceding description. Plate X. fig. 1. represents the scale. A A is the principal brass rule, upon the under side of which the frame *a a a a a a'* is adjusted by the screws *b b*, and which supports upon its bent extremity *c*, the arm B moving upon the centre *d*, and terminating in the arc of the circle *e e*.

C C is the lighter arm moving upon the centre *f* upon the arm B, and carrying at one end the nonius *g*, and at the other the steel point *h*, the distance of which from the centre *f* is exactly half an inch or one-tenth of the radius *f g*, and equal to the distance of the two centres *f d*. *i* is a small lens represented as lying down, but which may be raised by the centres *k* and *l* perpendicularly above the nonius to facilitate the reading. *m m* is the steel spring, which being fixed in a cavity cut out of the arm B, presses upon a small pin *n* on the arm C, and throws the radius back to the commencement of the arc.

Fig. 2. represents the register. D D D D is the black-lead bar, with its cavity *o o*. At *p p p p* it is cut away to the depth of half the bore. *q q* is the porcelain index, which is placed upon the top of the metallic bar, and confined to its place by the pressure of the platinum strap *r* acting by the force of the small porcelain wedge *s*.

When an observation is to be made, the metallic bar is placed in the cavity of the register, the index is to be pressed down upon it and firmly fixed in its place by the platinum strap and porcelain wedge. The scale is then to be applied by carefully adjusting the brass rules to the sides of the black-lead bar, and fixing it by pressing the cross piece (a') upon the shoulder: holding the whole together steadily in the left hand, the moveable arm should be so placed that the steel point (*h*) of the other leg of the compasses may rest upon the edge of the porcelain index, against which it will be pressed with some force by the spring: then moving the arm gently forward with the right hand, the point will slide along the end of the index till it drops into a small cavity (*t*) formed for its reception, and which exactly coincides with the axis of the metallic bar in the register, and the centre of motion of the compasses on the brass rule. The minute of the degree must then be noted, which the nonius indicates upon the arc. A similar observation must be made after the register has been exposed to an increased temperature and again cooled; and the number of degrees or minutes which the nonius will then mark will, by a simple calculation from the known length of the radii and angle, give the length of the chord comprised between the original position of the compasses and the point to which they have moved, or the distance which the index has been forced forward. Such an operation appears complex in the description, but is in fact extremely simple after a little practice, and does not require more than a few seconds for its performance. The scale of this pyrometer being completely

detached from the part which is exposed to the fire, obviates one important objection which has always been made to other contrivances of the same nature, from the uncertain degree of heat and expansion to which they are liable; while the simplicity of that part of the arrangement which alone is subjected to great heats, renders it little liable to injury; and together with the cheapness of the materials of which it is constructed, occasions but a very trifling expense for replacing it when injured.

The calculation of the absolute expansion of the bar indicated by the scale may be performed as follows:—As radius to double the sine of half the arc read off, and found in a table of natural sines, so will the radius B be to the chord of the same arc; and this divided by ten (the radius of B being ten times the length of the radius *f h*) will give the length required. Suppose the arc read off upon the scale to be 4°,

$$\text{then } \underset{\text{Radius.}}{1.0000000} : \underset{\text{Sine of } 2^{\circ}.}{0348995} \times 2 :: \underset{\text{Inches.}}{5} : \underset{\text{Inch.}}{.3489950} \div 10 = .0348995.$$

Now in working out this proportion it will be observed, that the multiplication by 2 and by 5 being both constant may, in conjunction with the division by 1.0, be omitted; and leaving out also the final division by 10, the case resolves itself into seeking the sine of half the arc, read off upon the scale, in a table of natural sines, and reading it as the decimal of an inch.

Moreover, the chords of small arcs are so nearly proportional to their arcs that, the number of degrees measured upon the scale never exceeding 10, they may be considered without sensible error as denoting equal increments of expansion. The following short Table of the value of a degree, and minutes of a degree, may therefore be useful in practice.

TABLE I.

°	′		Inch.
1	0	=	.00872
0	30	=	.00436
0	20	=	.00290
0	15	=	.00218
0	10	=	.00145
0	5	=	.00072
0	2	=	.00029
0	1	=	.00014

The chord of ten degrees derived from this Table by multiplying .00872 by 10 would therefore be .0872, whereas it is more accurately .0871; but the difference being only $\frac{1}{10,000}$dth of an inch may, in most cases, be disregarded.

I shall now proceed to show the degree of confidence which may be placed in this new pyrometer, by comparing the result of its indications with those of the best experiments upon the expansion of metals. Those of MM. Dulong and Petit* are well adapted to this purpose. These able philosophers, in their celebrated prize Memoir on the Measure of Temperatures, and on the Laws of the Communication of Heat, have given, from experiment, the expansion of rods of platinum and iron at different intervals between the freezing point of water and the boiling of mercury. Their mode of experimenting was unexceptionable; but it is to be regretted that they have not corrected their final results for an error of calculation which has been pointed out by Mr. Crichton†, which is by no means unimportant to the reasoning which they have founded upon them. The error, however, affecting the amount of expansion in volume, is reduced to one-third in the linear expansion, which is the subject of the present investigation, and may therefore be disregarded.

The following Table of the expansion of iron and platinum is extracted from their work.

Table II.

Temperature deduced from the dilatation of Air.	Mean absolute dilatation of Iron for 180 degrees.	Mean absolute dilatation of Platinum for 180 degrees.
From 32° to 212°	$\frac{1}{28200}$	$\frac{1}{37700}$
From 360° to 572°	$\frac{1}{22700}$	$\frac{1}{36300}$

Whence we deduce the linear expansion of platinum for 180° Fahrenheit, from 32° to 212° .00088420: and for 180°, from 360° to 572° .00091827: and of iron, from 32° to 212° .00118203: from 360° to 572° .00146842, showing an increasing dilatation in each when referred to an air-thermometer.

The bars of the different metals used in the following experiments were all exactly 6.5 inches in length.

Exp. 1. A square bar of platinum $\frac{2}{10}$ths of an inch thick, was carefully arranged in the black-lead register, which was placed in the apparatus represented, upon

* Ann. de Chimie et Physique, vii. 113. † Annals of Philosophy, New Series, vol. vii. p. 241.

a diminished scale, at fig. 3. *a* is an iron tube about two inches diameter, and closed at the bottom: *b* is a black-lead tube closed at the top, and fitted to the mouth of the former by grinding: *c* is a smaller black-lead tube projecting from the side of the latter near its upper end, and likewise fitted to its place by grinding. The whole forms a kind of alembic, which may be readily put together, and in which mercury may be easily boiled on a common fire, and the vapours collected without loss or annoyance to the operator. The register was fixed in its place by a wire, so that when mercury was poured into the iron bottle it was prevented from floating. The mercury in this experiment rose a little above half the length of the register. The whole apparatus was then placed upon a fire, and in ten minutes the mercury began to boil: in ten minutes more it freely distilled over; and in ten minutes further the apparatus was removed, the register taken out and allowed to cool. The arc measured upon the scale was in this instance 1° 17′.

The experiment was repeated, merely having the head of the alembic off, and suffering the mercury to boil freely in the iron bottle for a quarter of an hour. The arc measured was 1° 23′.

The register was next allowed to float upon the mercury, so that when the head of the alembic was adjusted and the mercury made to boil, it was not immersed in the metal, but surrounded by its vapour: the reading was 1° 16′. A repetition of this arrangement gave 1° 23′.

In another repetition of the experiment, the time was extended to twenty minutes from the first boiling of the mercury; the reading of the scale was 1° 20′.

Again; the time was reduced to ten minutes, and the measurement was 1° 23′.

In the various repetitions of this experiment the mercury freely distilled over, and the temperature was such, that every part of the black-lead tubes, in which the vapour circulated, would just scorch, but not blacken, a piece of writing paper held against them.

The following Table collects these results into one view, and exhibits the expansion denoted by each reading, and the mean result.

TABLE III.

	1° 17′	=	.01119
	1 23	=	.01206
	1 16	=	.01105
	1 23	=	.01206
	1 20	=	.01163
	1 23	=	.01206
Mean	1 20	=	.01163

The temperature of the atmosphere was about 64° during these observations.

EXP. 2. A bar of soft iron, of the same dimensions as that of platinum, was substituted for the latter in the register. The experiment was repeated five times; twice with the register immersed in the mercury, and three times exposed only to the vapour. The time of exposure varied from twenty minutes to ten, from the first moment when the metal began to boil.

The following Table exhibits the several readings and the appropriate expansions.

TABLE IV.

	2° 13′	=	.01933
	2 33	=	.02224
	2 10	=	.01890
	2 23	=	.02079
	2 20	=	.02036
Mean	2 20	=	.02036

The greatest variation from the mean was therefore only $\frac{6}{10,000}$dths of an inch in the platinum experiment, and $\frac{13}{10,000}$dths in the iron.

We shall now compare these results with the preceding determinations of MM. DULONG and PETIT.

The expansion of Platinum.

		Length of Bar.	
From 32° to 212°	= .00088420	× 6.5 . . .	= .005747300
From 360° to 572°	= .00091827	× 6.5 . . .	= .005968755
			.011716055
From 212° to 360°	= Mean of the above . . .		= .005858027
Total expansion from 32° to 572°			= .017574082

Add for the expansion from 572° to 660°,

the temperature of boiling mercury, calculated at the highest rate:—

180° : .005968755 : : 88° : .002918058 . . =.002918058

.020492140

Deduct expansion for 32°, the experiment with the pyrometer having been made at 64° . . . . = .001021742

Calculated at the lowest rate:—

180° : .005747300 : : 32° : .001021742

Real expansion of the bar by Dulong and Petit = .019470398

If from the real expansion thus obtained 01947

We deduct the apparent expansion obtained by the pyrometer .01163

The remainder .00784

will be the expansion of the black-lead.

The expansion of Iron.

		Length of Bar.	
From 32° to 212°	= .00118203	× 6.5 . . .	= .007683195
From 360° to 572°	= .00146842	× 6.5 . . .	= .009544730
			.017227925
From 212° to 360°	= Mean of the above . . .		= .008613962
Total expansion from 32° to 572°			= .025841887

Add for the expansion from 572° to 660°,

the temperature of boiling mercury, calculated at the highest rate:—

180° : .009544730 : : 88° : .004666311 . = .004666311

.030508198

Deduct expansion for 32°, the experiment with the pyrometer having commenced at 64° . . . = .001365901

Calculated at the lowest rate:—

180° : .007683195 : : 32° : .001365901

Real expansion of the bar by Dulong and Petit . .029142297

From the real expansion	.02914
Deduct the apparent expansion obtained by the pyrometer	.02036
The remainder	.00878

is again the expansion of the black-lead as obtained by this series of experiments.

Expansion of 6.5 inches of Black-lead.

From 64° to 660° by platinum bar	.00784
by iron bar	.00878
Mean	.00831

either determination differing from the mean by less than $\frac{5}{10,000}$dths of an inch.

This close agreement in results from two metals whose expansions differ so much from each other is highly satisfactory; but the great delicacy of the instrument may be still better appreciated from the following experiment of the expansion of nine different metals from the temperature of 62° (the temperature of the air at the time of observation) to 212°.

Exp. 3. Bars of the following metals were successively placed in the register and immersed in hot water, which was gradually heated to the boiling point, and kept boiling for ten minutes in each instance. The following Table exhibits the readings of the scale and the appropriate expansions.

Table V.

	°	′			
Platinum . .	0	19	=	.00276	from 60° to 212°
Iron (soft) . .	0	35	=	.00508	————
Copper . . .	0	47	=	.00683	————
Tin (grain). .	0	56	=	.00814	————
Zinc	1	40	=	.01454	————
Lead. . . .	1	25	=	.01223	————
Brass . . .	0	55	=	.00799	————
Gold (fine). .	0	36	=	.00552	————
Silver (fine) .	0	56	=	.00814	————

In the subsequent Table I have given the absolute expansions of the same metals from 32° to 212° from the best authorities; and for the sake of compa-

rison have added from calculation their expansion from 62° to 212°, by reducing the former in the proportion of 180 : 150.

TABLE VI.

	Length of Bar.	From 32° to 212°.	From 62° to 212°.	Authorities.
Platinum	.00088420 × 6.5 =	.005747300 =	.004789416	DULONG & PETIT.
Iron .	.00118203 × 6.5 =	.007683195 =	.006402662	DULONG & PETIT.
Copper	.00171821 × 6.5 =	.011168365 =	.009306970	DULONG & PETIT.
Tin .	.00217298 × 6.5 =	.014124370 =	.011770308	LAVOISIER & LAPLACE.
Zinc .	.00294200 × 6.5 =	.019123000 =	.015935833	SMEATON.
Lead .	.00284836 × 6.5 =	.018514340 =	.015428616	LAVOISIER & LAPLACE.
Brass .	.00193000 × 6.5 =	.012545000 =	.010454166	SMEATON.
Gold .	.00146606 × 6.5 =	.009529390 =	.007941158	LAVOISIER & LAPLACE.
Silver .	.00190974 × 6.5 =	.012413310 =	.010344424	LAVOISIER & LAPLACE.

Upon deducting from the amount of these several absolute enpansions the apparent expansions in the black-lead register, we shall obtain the expansion of the latter from 62° to 212°, as derived from the several metals. The results are comprised in the following Table.

TABLE VII.

	Expansion of the Metal Bars.	Expansion of Black-lead Register.	Difference from Mean.
Platinum . .	absolute .00478 apparent .00276	=.00202	−.00032
Iron	absolute .00640 apparent .00508	=.00132	−.00102
Copper . . .	absolute .00930 apparent .00683	=.00247	+.00013
Tin	absolute .01177 apparent .00814	=.00363	+.00129
Zinc	absolute .01593 apparent .01454	=.00139	−.00095

TABLE VII. (Continued.)

	Expansion of the Metal Bars.	Expansion of Black-lead Register.	Difference from Mean.
Lead . . .	absolute .01542		
	apparent .01223		
		. . =.00319 . .	+.00085
Brass . . .	absolute .01045		
	apparent .00799		
		. . =.00246 . .	+.00012
Gold . . .	absolute .00794		
	apparent .00552	. . =.00242 . .	+.00008
Silver . . .	absolute .01034		
	apparent .00814		
		. . =.00220 . .	−.00014
		Mean .00234	

In five instances out of these nine, the difference of the expansion of the black-lead from the mean does not exceed $\frac{32}{100,000}$dths of an inch, two being in deficiency, and three in excess: and it is worthy of observation that they are the metals whose dilatations have always been considered the most regular, and concerning which there is the least difference of authorities, viz. gold, silver, platinum, copper, and brass. The greatest difference is in the tin, which amounts to nearly $\frac{13}{10,000}$dths of an inch in excess; and it is more than probable that the absolute expansion of this metal has not hitherto been obtained with sufficient precision, and that it even varies in different states. I shall return to this subject in the second part of this Paper, which I reserve for a future communication; in which I hope to be able to lay before the Society observations and tables of the dilatations of metals to their melting points. It is my intention in this first part to touch no further upon the subject of expansion than is sufficient to establish confidence in the pyrometer as a measure of heat.

Another confirmation of the precision of these observations may be derived by calculating the expansion of the black-lead register for the 150°, from the greater expansion previously determined by the boiling point of mercury for

$$596° : .00831 :: 150° : .00209$$

which only differs $\frac{25}{100,000}$dths of an inch from the above mean.

Exp. 4. It was a principal object to ascertain whether any and what difference existed in the expansion of different specimens of the black-lead earthenware: two or three registers which I had cut out of the same crucible gave me almost identical results by exposure to boiling mercury. I then selected another specimen by a different manufacturer. Its grain was very fine, and its texture more close and compact than the former. It was twice exposed with the platinum bar to boiling mercury. The first time it was boiled for a quarter of an hour, and the arc measured was 1° 45′. The second time the boiling was continued for only ten minutes, and the reading was precisely the same. The expansion was therefore .01526.

Absolute expansion as before	.01947
Apparent expansion	.01526
Expansion of black-lead	.00421

Exp. 5. The same register of the fine-grained black-lead was exposed for a quarter of an hour with the iron bar to boiling mercury: the arc measured on the scale was 2° 49′ = expansion .02457.

Absolute expansion as before	.02914
Apparent expansion	.02457
Expansion of black-lead	.00457

Fine-grained black-lead by platinum . .	.00421
by iron . . .	.00457
Mean .	.00439

The two experiments differing from the mean by less than $\frac{2}{10,000}$dths of an inch. This shows that the fine-grained ware expands less than the coarser, and proves the necessity of ascertaining the expansion of each register for itself by boiling in mercury; at least till some means be taken to insure their uniform composition. Every register should also be marked with a reference to its proper expansion; and I would recommend all those who may use the instrument for delicate researches, to verify this point for themselves; as they may easily do with the apparatus before described.

Exp. 6. The expansion of the last specimen of black-lead ware being nearly the least which has fallen under my observation, I repeated with it the experiment of the dilatation of six of the former list of metals to the boiling point of water; as the accuracy of these observations is a point which it is of the greatest importance to establish.

The subjoined Table contains the results.

Table VIII.

Platinum . .	0° 22′	= .00319	from 60° to 212°
Iron	0 39	= .00566	———
Copper . . .	0 54	= .00785	———
Brass . . .	0 59	= .00857	———
Gold	0 41	= .00595	———
Silver . . .	0 58	= .00843	———

The differences of the observed expansions and the real are also subjoined and ranged by the side of those obtained by the first series of observations.

Table IX.

	Expansion of the Metal Bars.	Expansion of Black-lead. Second Series.	Differ. from Mean.		First Series.	Differ. from Mean.
Platinum	absolute .00478 apparent .00319	=.00159	.00000	. .	.00202	−.00032
Iron . .	absolute .00640 apparent .00566	=.00074	−.00085	. .	.00132	−.00102
Copper .	absolute .00930 apparent .00785	=.00145	−.00014	. .	.00247	+.00013
Brass . .	absolute .01045 apparent .00857	=.00188	+.00029	. .	.00246	+.00012
Gold . .	absolute .00794 apparent .00595	=.00199	+.00040	. .	.00242	+.00008
Silver .	absolute .01034 apparent .00843	=.00191	+.00032	. .	.00220	−.00014
	Mean .	.00159	. . . . .	. .	.00234	

The agreement of this second series with each other is quite as close as that of the first; and it is worthy of remark, that the greatest variation from the mean is in both cases with the iron in deficiency, and nearly to the same amount of one half. It is not unlikely, therefore, that there may be some error in estimating the absolute dilatation of this metal, which is probably something greater than we have assumed.

If we estimate the expansion for these 150° to the boiling point of water from the result obtained by the boiling of mercury, we shall have the following proportion:— 596° : .00439 : : 150° : .00110
which does not differ quite $\frac{5}{10,000}$dths of an inch from the foregoing mean.

Having thus, I trust satisfactorily, established the accuracy of the pyrometer, and the degree to which confidence may be placed in its indications, I shall conclude this part of my subject with the details of some experiments upon the fusing points of different metals. I shall designate the registers of coarse and fine-grained black-lead respectively by the letters A and B.

Exp. 7. About 30lbs. of the clippings of thin sheet copper were very gradually melted in a crucible in the blast furnace of the Royal Institution. The platinum bar was adjusted in the register B, and when the metal was about half run down, it was placed perpendicularly with the index upwards in the crucible, and held down with a pair of tongs. The crucible was then gradually fed with the clippings till the melted metal covered about two-thirds of the register. In this situation it was kept ten minutes, and when it was lifted out some of the metal remained unmelted. A crust of oxide, mixed with metal, had also affixed itself to the upper part of the black-lead. This was partially dissolved away and loosened by immersing the register with great care, when cold, in a diluted mixture of sulphuric and nitric acids. The whole was thus easily removed, and the black-lead exhibited a perfectly clean surface. The arc measured upon the scale was 5° 49′, denoting an expansion of .0508. The temperature of the laboratory was about 65°.

I am indebted to the kindness of Mr. Mathison for unexceptionable opportunities of taking the melting points of gold and silver at the Royal Mint, who also most obligingly assisted me in the operations. Two new registers were prepared, which I shall designate as II and III: their rates of expansion were not determined till after the experiments.

Exp. 8. The register II was carefully adjusted with the platinum bar.

About 90lbs. of fine gold were weighed, and one of the ingots was cut into ten pieces for the purpose of gradually feeding the crucible, and keeping the temperature down to the true melting point during the observation. The remainder was melted in a black-lead crucible in a wind-furnace. When just fused, one of the pieces was thrown in, and the melted metal immediately congealed upon the surface. The register, which had been slowly heated in another crucible to a dull red, was then taken up with a pair of tongs and plunged perpendicularly into the gold about two-thirds of its height. In this situation it was kept ten minutes, and during the time two more lumps of the metal were thrown in. It was then carefully lifted out and set apart to cool. Its surface was perfectly clean, only a few small globules adhering to it, which were easily removed. I may here remark that stirrers of the black-lead earthenware are constantly used at the Mint for agitating the melted gold. The arc measured from this experiment was 6° 10′, equivalent to an expansion of .0537. Temperature of the air about 65°.

Exp. 9. The register III was fitted with the iron bar, and also heated to a dull red. The temperature of the melted gold was prevented from rising by constant feeding with the pieces; the crucible being never left without some portion unmelted. It was then plunged beneath the surface of the metal as in the preceding experiment, and held in that situation for ten minutes. The arc measured was 9° 2′, indicating an expansion of .0787.

Exp. 10. The rates of expansion of the two last registers were determined by boiling them for ten minutes each in mercury. The results were as follow:

	Arc.		Expansion.
II with the platinum bar	1°.50	=	.0159
III with the iron bar	2°.38	=	.0229

Exp. 11. About 50lbs. of pure silver were melted in a black-lead pot: a little scum floated upon the surface, which appeared at first like drops of oil upon a basin of water. I was afterwards informed that the metal had been refined with nitre, and the dross was owing to the action of a little remaining potash upon the crucible. Two registers had been prepared for the platinum and iron bars; but the observations were lost from the same action upon their substance. They were so deeply corroded in a line which corresponded with the level of the fluid metal, as to render it impossible to apply the scale, with any certainty, to their surfaces.

Exp. 12. Two new registers were selected, whose rate of expansion was

found by boiling in mercury to be equal; the arc in both cases being with the platinum bar $1° 20' = .0116$. They were marked IV and V.

IV was adjusted with the platinum bar. An ingot of silver, which had been refined by cupellation, weighing about 35lbs., was placed in a black-lead crucible in a wind-furnace. When somewhat more than three-fourths were melted, the register, previously heated to a dull red, was plunged into it as before, and held down for ten minutes. When lifted out its surface was found perfectly good, and the few adhering globules of metal were easily removed. When cool the scale was applied, and the arc found to be $4° 10' =$ expansion .0363. Temperature of the air 65°.

Exp. 13. The iron bar was placed in the register V, and having been previously heated was plunged into the same pot of metal. The silver at first set about the black-lead and adhered to it in a large lump. At the expiration of ten minutes this was just melted off, and the instrument was raised out of the crucible in a perfectly clean state. When cool the arc measured was $7° 24' =$ expansion .0645.

Exp. 14. I made several attempts at the Royal Institution to ascertain the melting point of cast iron; but owing to the large quantity of the metal necessary; to the difficulty of keeping the temperature steady by constant feeding; and to the failure of crucibles,—I did not succeed. I am under obligation to Mr. Parker of Argyle Street, for the readiness with which he afforded me every facility of performing the experiment at his foundry.

I selected a new register for the occasion, which was marked I. Its rate of expansion was not determined till after the experiment. A crucible was prepared capable of containing about 35lbs. of the metal. It was filled with pieces of the best grey iron, and placed in a powerful wind-furnace, which admitted of the operator standing immediately above the crucible with complete command over it. When the metal was melted, the crucible was lifted from the furnace, and the dross skimmed off its surface. It was then replaced; a lump of the same iron was thrown into it, and the register, previously heated red hot, was immersed in the fluid to about the same depth as in the former experiments. It was kept in this situation by means of a pair of tongs for ten minutes, and afterwards gently lifted out and laid upon hot sand. A thin scale of iron adhered to the black lead, which when cold was easily removed,

and retained the form of the bar like a sharp cast, and left the surface of the register perfectly clean and bright. The arc measured after the experiment was 6° 16′ = expansion .0546. Part of the lump of metal remained unmelted.

Exp. 15. Another register, which had been prepared with the iron bar, was immediately immersed in the fluid metal. The fire, however, had been allowed to fall, and the iron almost instantly congealed; and in attempting to lift the register out, it was found to be set fast and broke. The experiment was so far instructive, that it proved how nearly the exact melting point had been attained in the preceding experiment. The iron bar was removed uninjured.

Exp. 16. The register I with the platinum bar was boiled in mercury for ten minutes: the arc afterwards measured was 1° 20′ = expansion .0116.

Exp. 17. About 30lbs. of zinc were carefully melted in a crucible set in a common fire, assisted with the bellows. The register A was prepared with the iron bar and held down in the metal, which was supplied from time to time so as to insure its very gradual fusion, and some portion always remaining in the solid state. In ten minutes time it was removed, and when cold the arc measured was 2° 45′, equivalent to an expansion of .0239.

A dry stick of deal plunged into the melted metal for a few seconds caused a violent ebullition, and was deeply charred. The zinc in this state did not appear red in the light.

Exp. 18. About 12lbs. of zinc were melted in a smaller crucible: the register B prepared with the iron bar was immersed in it; but instead of being gradually supplied, the heat was allowed to increase after fusion till it began to burn: at this point there was an evident blush of red upon its surface. The arc measured upon this occasion was 4° 7′ = expansion .0358.

I shall now collect together the results of the preceding experiments, for the purpose of showing what conclusions may be derived from them with regard to the degrees of temperature which they indicate when referred to the common thermometric scale. I shall make the calculations first upon the supposition that equal amounts of expansion denote equal increments of temperature; and I shall thus be enabled to compare the present series with that which I formerly obtained with my first pyrometer, and to offer a few remarks upon the differences of the two.

I shall adopt the corrected temperature of 662° (350° Centigrade) for the boil-

ing point of mercury, as proposed by MM. Dulong and Petit; which agrees very closely with the amount employed in my first calculations, and which, deducting 62° for the mean temperature at which my experiments commenced, gives 600° for the interval for which the several expansions were determined.

The first column of the following Table refers to the number of the experiment; the second to the mark of the register and the bar which was employed; and the third to the amount of expansion in the same, occasioned by boiling mercury or 600° of temperature upon Fahrenheit's scale. The fourth column exhibits the arc measured upon the scale; and the fifth the equivalent expansion. The sixth contains the corresponding temperature; the seventh records the state of the metal, which was the object of the experiment; and in the eighth I have recapitulated the corresponding results of my former Essay.

Table X.

No. of Experiment.	Mark of Register and Bar.	Expansion for 600°.	Arc measured on Scale.	Expansion.	Temperature.		Metals observed.	Temperature by former Pyrometer.
7	B Platinum	.0152	5° 49′	.0508	2005+65	2070°	Copper, fusing point.	2548°
8	II Platinum	.0159	6 10	.0537	2026+65	2091	Gold, fusing point.	2590
9	III Iron	.0229	9 2	.0787	2061+65	2126	ditto ditto	
12	IV Platinum	.0116	4 10	.0363	1877+65	1942	Silver, fusing point.	2233
13	V Iron	.0203	7 24	.0645	1906+65	1971	ditto ditto	
14	I Platinum	.0116	6 16	.0546	2824+65	2889	Iron, fusing point.	3479
17	A Iron	.0203	2 45	.0239	708+65	773	Zinc, fusing point.	648
18	B Iron	.0245	4 7	.0358	876+65	941	Zinc, inflaming.	

The most remarkable fact displayed by the preceding comparison is the beautiful accordance of the results obtained from two metals whose expansions are so different as those of platinum and iron. The temperature indicated by the latter exceeds that by the former in the instance of the fusing

point of gold 35°, and in that of silver only 29°; and this excess is in accordance with the conclusion of MM. DULONG and PETIT, exhibited in Table II., that the expansion of iron increases in the higher degrees in a greater proportion than that of platinum.

The discrepancy between the temperatures derived from the observations with my first pyrometer and the present are considerable, but may be sufficiently accounted for by the differences in the circumstances of the experiments, without imputing inaccuracy to the instrument. In the paper to which I have before alluded, I stated that "I did not offer the results as positive and accurate determinations of the different degrees, but only as nearer approximations than any that had yet been furnished from actual observation. The only method which I had it in my power to adopt for the purpose, I do not consider to be susceptible of absolute accuracy. The arrangement made consisted of a muffle of black-lead placed in an excellent draught-furnace. This muffle was furnished with a door, through a round hole in which the stem of the pyrometer was passed up to the shoulder. Another door, which could be stopped at pleasure, admitted a full view of the interior. The metal to be tried was placed in a small black-lead receptacle, of the same thickness as the pyrometer tube, in the middle of the muffle. Now it is evident that the pyrometer so situated would indicate the mean heat of the whole of the muffle; which heat might, and did, vary in different parts. Of two pieces of silver of the same size placed within an inch of each other, one fused some time before the other." I also suggested that "means might be contrived to surround the instrument with the metal in a state of fusion; but that it required particular opportunities, which it was to be hoped that those would avail themselves of who had them in their power."

That the latter method is the only one which can admit of accuracy will be evident from a few reflections. Setting aside the inequality of the heat of different parts of the same heated muffle, which however is a consideration of the utmost importance, it is obvious that its temperature must considerably exceed the true melting point of the metal exposed to its influence. Just as a piece of ice would never melt in a chamber of the temperature of 32°, but would require a considerably higher heat in proportion to its mass to supply the caloric which becomes latent during the process,—a mass of iron would

exhibit but little signs of liquidity till subjected to a heat much above its true point of fusion. When once in a liquid state, both would rapidly rise to the temperature of the medium to which they were exposed. When metals are melted for the purposes of the arts, they of course require to be heated very far beyond their fusing points, that they may flow into the minutest fissures of the moulds in which they are cast, notwithstanding the cooling influences to which they are suddenly exposed. In some of the finer castings of brass, the perfection of the work depends upon the intensity to which the metal is heated, which in some cases is urged even beyond the melting point of iron. With a fire whose power in all cases must so greatly exceed the temperature required, it is necessary to bestow great care in supplying the metal gradually, as we have before described; as it is inconceivable with what rapidity it rises after the solid pieces are completely dissolved. Evidence of the same fact may be derived from the experiments of MM. Clement and Desormes, which I have before quoted. They calculated the heat of melted iron at 3988°, and of iron just on the point of melting at 3164°,—a difference of 800°. And it is clear from the circumstances of the experiment, that the former must have considerably exceeded the true melting point, or it never could have been transported in a liquid state from the crucible to the apparatus in which the water was heated or the ice melted. It is probable that the process which they employed, of the calorimeter, was not susceptible of great accuracy; but the discrepancy of the results from those which I obtained from the metal in analogous circumstances is not great.

Iron just melting	3164°	by the former
	2889	by Pyrometer
	——	275° difference.
Iron melted at a high heat .	3988	by the former
	3479	by Pyrometer
	——	509° difference.

A similar excess also appears in their determination of the heat of melted copper, and obviously admits of the same explanation.

After performing these experiments upon the melting points of the metals, I was desirous of ascertaining the effects of the most intense heat which it was possible to produce in a furnace; and to measure the utmost limits of expansion

in a platinum bar. For this purpose I made use of an excellent wind-furnace in the Royal Institution, in which upon former occasions hob-nails had been completely fused into a button.

Exp. 19. The register I, which had not been the least injured by the previous experiments, was fitted with a new bar of platinum, which had been drawn as a wire, was $\frac{5}{20}$ths of an inch in diameter and very ductile. The iron bar was also adjusted to a new register, and both were placed upright in a well heated crucible. About half an inch of powdered charcoal was strewed upon the bottom to prevent any adhesion; and two soft iron nails, and a piece of unglazed Wedgwood's porcelain, were thrown in for the purpose of affording some indication of the degree of heat attained. The crucible was then set in the furnace, another smaller crucible inverted upon it, covered with coke, and the heat urged to the utmost for two hours. The fire was suffered to burn out, and the crucible with its contents removed for examination. It was sound, but the luting had been completely fused. The nails were found melted into two complete buttons, and the porcelain was partially fused upon the surface.

The register I appeared to be uninjured, but the platinum ring and wedge were loose, evidently from a contraction having taken place in the substance of the black-lead. This was no doubt owing to the heat having exceeded that at which it had been originally baked. The amount of expansion consequently could not be measured. The platinum ring, both of this and the other register, exhibited a remarkable change of texture; they had become very rough and crystalline, and were perfectly brittle, breaking easily between the fingers. The platinum bar also, which there was some difficulty in removing from the cavity, presented a very extraordinary appearance. It was apparently embossed with crystals, and was evidently larger at the lower end than at the top: it was also something contracted in length. Upon examination with a lens no regular facets could be detected, but it had the appearance of a bar constructed of plates of native platinum loosely welded together.

The register which contained the iron bar was considerably bent, and had several transverse clefts in its substance, owing possibly to its having become inclined in the crucible. Partial fusion had taken place upon the surface of the bar, which had run down and formed a knot at its lower extremity. About

an inch of the same end was found to have been converted into steel, but all the rest retained the character of soft iron.

Exp. 20. I repeated the last experiment with the same platinum bar in the register I. The arrangement was precisely the same, with the exception of the second register with the iron bar, and the fire was maintained with equal intensity for an equal time.

The iron nails were found perfectly melted, and the porcelain superficially fused as before. The ring and wedge, however, were fixed in their places, and the index undisturbed, but the measure was unfortunately lost from an accident. The texture of the platinum ring was changed, as in the previous experiment, and the bar tightly fixed in the cavity. By frequent gentle concussions it was removed without injury to the black-lead, which had some slight marks of fusion upon its surface, but was in a perfectly good condition. The bar was in a still rougher state than before, highly crystalline, and exhibited several large longitudinal clefts in its substance. It was found, by measurement with callipers, to be $\frac{1}{20}$th of an inch larger in diameter at its lower than at its upper end, and seemed to be approaching a state of complete disintegration. It was, however, perfectly hard and inflexible. My intention was to have again exposed it for several hours to the same degree of heat, with the expectation that the disintegration would have been complete, and that it would actually have fallen in pieces during the operation: in the mean time I chanced to make it red hot upon a common charcoal fire; and upon attempting to lay hold of it with a pair of tongs the two ends dropped off, and I only withdrew the small portion which I had grasped, and which was flattened and fractured by even this slight compression. The two ends were afterwards carefully, but with difficulty, raised from the fire, and when cold were perfectly hard and inflexible. I again heated a portion of the bar to a dull red, and it crumbled to powder from a slight blow with a hammer.

Exp. 21. It being a point of the greatest interest to ascertain the maximum of expansion which took place in the platinum previous to this remarkable change of structure, I adjusted the original platinum bar, with which the greater part of my experiments had been made, and which presented a perfectly smooth surface, and was very soft and ductile, in the register I. A crucible was placed in the same wind-furnace, containing only a little charcoal

powder, with the iron nail and fragments of porcelain as test pieces. The fire was urged to the utmost; and when it had been continued two hours the cover was removed, and the register, previously made red hot, was carefully introduced, the cover replaced, and the ignited fuel heaped upon it. At the expiration of a quarter of an hour it was lifted out and cautiously cooled. An excellent measure was obtained, and the arc determined to be 7° 24′ = expansion .0645.

The test pieces were found in the same state as in the previous experiments. The platinum bar was loose in the cavity, and had not altered its form; but its surface had assumed a slightly crystalline texture, and it had become very hard and inflexible.

The expansion registered would, upon the hypotheses before assumed of equal amounts of expansion denoting equal increments of temperature, indicate a heat of 3336°; or, adding the initial temperature 65°, = 3401°. But it must be remembered that this is probably rather the temperature at which the change in the structure of the platinum took place, than the utmost heat of the furnace. The latter may possibly exceed the degree at which the expansion of the metal ceases, and at which its particles evidently form a new arrangement; but this point cannot at present be determined. The coincidence of this result with that obtained in the former series of my experiments, is very remarkable. The temperature at which I obtained the fusion of cast iron at that time was calculated at 3479°, and was produced by the utmost energy of an excellent wind-furnace; and this, it will be observed, is within 80° of the present maximum.

Exp. 22. Being desirous of ascertaining whether the register and platinum bar had undergone any change in their rates of expansion by the intense heat to which they had been exposed, I again adjusted the latter in the register I, which had now been once immersed in melted iron, and three times subjected to the action of the wind-furnace, and boiled them for ten minutes in mercury. The arc measured was 1° 19′ = expansion .01148: the difference of 1′ may safely be ascribed to the uncertainty of the reading.

The temperatures thus determined will require correction, if we adopt the conclusion derived from the experiments of MM. Dulong and Petit,—that the dilatability of solids, referred to an air-thermometer, increases with the heat.

The amount of this correction will be as the rate of increase; and according to those gentlemen is 11°.6 of the Centigrade thermometer, or 20°.8 FAHR. from 32° to 572°, or the calculated temperature is to the true as .00091827 : .00088420. Supposing the increase of dilatability to continue the same for equal intervals of temperature, which however has not yet been proved, the following Table will exhibit the corrected temperatures derived from the preceding experiments with the platinum bar.

TABLE XI.

		Observed.	Corrected.
Melting point of	Silver	1942	1873*
———	Copper	2070	1996
———	Gold	2091	2016
———	Iron	2889	2786
Temperature of the maximum of expansion of	Platinum	3401	3280

If we reason in the same way from the increase of the dilatation of iron, as laid down by the same authors, the discrepancy between the temperature derived from the platinum and iron is very considerable; the melting point of silver coming out 1682°, and that of gold 1815° by the latter: but I conceive that the determination of this point in the iron is open to objections which do not apply to the platinum, and my suspicion is confirmed by the anomalous expansion of the iron exhibited in Tables V. and IX., and to which I shall recur upon a future occasion.

The general utility of the pyrometer, however, will in no way be affected by any uncertainty in these corrections. The indications which it is capable of affording will always be positive determinations, which it will be easy to modify by calculation, as our theories may improve. For all common purposes (and I must own that I look forward with hope that this instrument will prove eminently useful in many of the common processes of the arts) it will not even be necessary to note the expansion indicated by the arc measured; but each minute of the degree may at once be valued in degrees of FAHRENHEIT's scale at the time of taking its rate of expansion by the boiling of mercury: and a

* Mr. PRINSEP, from a laborious series of experiments upon the expansion of air confined in a bulb of gold, determines the melting point of silver to be 1830°.—Phil. Trans. 1828. p. 94.

Table of such values should be furnished for each register by the maker of the instrument. The following, for example, would be the proper Table for register I, which has been so often referred to, in which the arc for the boiling of mercury or 600° (without adding the initial temperature) was 1° 20′.

TABLE XII.

°	′		Expansion.		Temperature.
1	0	=	.00872	=	450°
0	30	=	.00436	=	225
0	20	=	.00290	=	150
0	15	=	.00218	=	112
0	10	=	.00145	=	75
0	5	=	.00072	=	37
0	2	=	.00029	=	15
0	1	=	.00014	=	7.5

With such a Table an intelligent workman could employ the instrument without any material error. Those who might object to the expense of a platinum bar may substitute an iron one for ordinary purposes, and the cost of the black-lead register can never be an obstacle to its general use. Other substances might obviously be employed in its construction, but the facility with which it can be worked, its small expansion, its infusibility, and the impunity with which it bears the most sudden changes of temperature (as when red hot it may even be quenched in water without injury), will probably always give the black-lead ware the preference. The only precaution to be taken with it is to expose it previously, out of the contact of air, to a heat at least as great as that in which it is intended to employ the instrument.